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ABSTRACT

A general framework is outlined for describing the relationship of cognition to brain systems. The model provides for empirical investigations at many levels--computational, chronometric, spatial imaging, and cellular--and argues for the logical interrelationship of these areas of investigation. It is applied to selective visual-spatial attention studies in which specific cognitive operations have been related to regional neural systems, by studying brain-injured patients. Studies with alert monkeys are also discussed. Studies of cross-modality cuing and interference suggest that the parietal system is also related to spatial orienting, irrespective of modality and type of cue. Thus a hierarchical cognitive system of spatial attention results, in which somewhat separate modality-specific systems are organized. Patient studies suggest that spatial attention is a module within a more general system of attention that extends to other cognitive systems, such as language. While the anatomy of the more general system is unknown, the general framework does suggest the types of studies which may be useful in revealing its anatomical organization. (GDC)

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How does the brain perform cognitive tasks? This chapter approaches the general issue by outlining a computational model of visual-spatial attention. Studies of alert animals, brain injured patients and normals suggest that components of this model are performed by separate cortical and midbrain systems which are orchestrated to produce covert attentional shifts. These findings suggest a distributed network view of visual-spatial orienting with the cognitive operations performed in different anatomical locations. Attention to visual, auditory and tactile modalities appear to involve separate anatomical systems

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Hierarchical Distributed Networks in the Neuropsychology of Selective Attention

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OUTLINE

I. Goal of the Chapter

II. Framework for linking cognitive and neural system

III. Computational analysis of visual-spatial attention

IV. Distributed neural systems underlying visual-spatial attention

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Hierarchical Distributed Networks in the Neuropsychology of Selective Attention

ABSTRACT

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Attention to visual, auditory and tactile modalities appear to involve separate anatomical systems at the lowest level. At a higher level attention can be allocated to a common cognitive system for spatial location. Studies of non-visual spatial attention suggest that this higher level also involves the parietal cortex.

Further studies suggest the presence of attentional systems which go beyond any single cognitive domain (e.g. spatial). However, our results show that attention to non spatial language information does not involve the parietal system so important for spatial orienting.

Hierarchical Distributed Networks in the Neuropsychology of Selective Attention

Michael I. Posner

In 1980 I was asked to give the Seventh F.C. Bartlett lecture. The topic was orienting of attention. My thesis was simply that it was possible to "measure time locked shifts of attention, both to central instructional cues and to changes in eye position with almost as much precision and ease as overt shifts of eye positon." I was enormously excited by these experiments, because I believed they were a powerful demonstration of the ability of cognitive psychologists to explore internal mental operations by careful time measurements.

Similar results had already been obtained in such well known experimental paradigms as letter matching (Posner, Boies, Eichelman & Taylor, 1969), memory scanning (Sternberg, 1966); mental rotation (Shepard & Metzler, 1971) and priming (Neely, 1977). All of these paradigms were intrinsically more interesting to cognitive psychologists than detecting light flashes in an otherwise dim field, which was the methodology employed in the experiments described in my 1980 lecture. Why then the excitement? It was because unlike the more complex situations, these new experiments were ones which could be and were being done in alert monkeys. The presence of an animal model seemed to me an opportunity to determine whether the results obtained from performance studies of normal humans converged with those using single cell methodology in the study

of spatial attention where both methods could be employed. If they did I felt it would be evidence that cognitive and neuroscience techniques could be used together to provide an integrated picture of how neural systems produce cognition. In 1980 I was forced to hedge seriously on this promise by stating: "there is nothing in our results that can prove that the spatial attention mechanisms that we study are identical to those under investigation in areas of the parietal lobe."

For the last five years I have been engaged in attempting to provide the missing proof,as part of an effort to bring together the studies of cognition and neuroscience. I believe our results do provide very substantial additional support to the common assumption of neuropsychology that neural systems support cognition and further suggest a view of how this is done in detail.

Framework

In the course of these studies it has been useful to view our studies in relationship to a very general framework for relating cognitive processes to neural systems. This framework is shown in Figure 1. The top two rows are at the level of cognitive

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Insert Figure 1

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science. They provide a description or sufficiency analysis of how any electromechanical system would be able to perform the cognitive task described. Students of cognitive science have developed a number of computational models for tasks such as visual imagery (Kosslyn, 1980), aspects of reading (McClelland &

Rummelhart, 1982); and, typewriting (Rummelhart & Norman, 1982). They provide a detailed view of the computations necessary to accomplish the cognitive task. These computational models consist of subroutines that we label elementary mental operations. They resemble the types of operations studied by performance experiments for the last twenty years (Posner, 1978). Sample operations include: match, store, zoom, compare, engage, and move. Each operation can be specified in terms of the input code to the operation and its output code. These operations often serve as labels of the box models of information flow which dominate text books in cognitive psychology.

How can we determine if these operations are ones actually carried out by people in the course of accomplishing cognitive tasks? To what extent are these mental operations a description of the mechanisms of human performance? There are several bases on which such a decision might be made. If we suppose that several different cognitive tasks involve the same operation we ought to expect performance in those tasks to be correlated across people (Chase, 1976; Keele & Hawkins, 1982). Unfortunately, there are also other reasons which might lead to such correlations, thus their existence is rather weak evidence. A more direct experimental test is to determine whether two tasks involving the same putative mental operation have strong interactions with one another. For example, if they need to be executed simultaneously, do they interfere with one another? If they are performed successively do they show a high degree of priming (Kinsbourne & Hicks, 1973)? These are objective, if

rather cumbersome, ways of checking whether the operations obtained from a sufficiency analysis describe human performance.

In our work we have often attempted to describe mental operations in terms of time locked facilitations and inhibitions accompanying their performance (Posner & Snyder, 1975). Methods for making such measurements had been described previously and have been widely applied (Jonides & Mack, 1984; Posner & Snyder, 1975). A great deal is known about how this can be done and what pitfalls there are in using them (Jonides & Mack, 1984).

Consider the act of encoding a visual word. According to many computational models this act involves operations which activate physical, orthographic, phonological and semantic codes. By studying patterns of facilitation in matches based on each of these criteria we have tried to separate such codes and determine whether they represent what happens as a word is processed (Posner, 1978). Similar methods have been applied to determine whether rotating a visual representation is accomplished by analog or propositional computations (Cooper, 1976). In order to determine, how people perform this operation Cooper (1976) studied the facilitation of probes rotated to varying angles as the subject attempted to mentally rotate a visual form. She found strong evidence that probe processing was facilitated when the rotating image was calculated to be at the same angle as the probe. These results argue that humans are performing an analog rotation at least to the degree of precision of the experiment. Thus, time locked facilitations and inhibitions allow us to describe some of the characteristics of on-line mental operations

as they are executed by people. This level of description is illustrated in the third row of Figure 1.

The use of the words facilitation and inhibition are biased to make one inquire whether such patterns are related to the activity of the populations of neural cells that might perform the computation. The third row of Figure 1 deals with facilitation only as more efficient processing in terms of the speed and accuracy with which the organism responds. These are facilitations in the performance domain, not necessarily in a neurophysiological sense. Similarly inhibitions in these studies means a reduction in efficiency of performance as measured by increased reaction time, raised threshold or some other performance measure.

To what extent are findings favoring facilitation and inhibition in the performance domain related to underlying changes in populations of neural cells? This issue may be examined in many ways. One major method for doing so is to relate the performance of cognitive operations with electrical changes which can be detected in the scalp EEG (Donchin, 1984). I have tried to review some of the encouraging results which suggest that components of the EEG do relate to rather specific mental operations (Posner, in press). For example, the general shift in performance efficiency following a warning signal is accompanied by a negative change in the EEG which has been termed the contingent negative variation. Under conditions of rapid presentation of stimuli to several channels, the instruction to attend to one channel produces a negative shift in that channel

with repect to the unattended channels which has been called processing negativity (Harter & Aine, 1984; Naatanen, 1982). Similarly the change in efficiency of detecting an expected letter versus an unexpected one is reflected in the latency of a late positive wave called the P300 (Duncan-Johnson & Donchin, 1982; Posner, 1978). These seem to me to constitute increasingly favorable evidence for the links between faciliation and inhibition in the performance domain and those present in electrical activity arising from the brain.

In addition new methods of exploring human brain activity can also be brought to bear on these issue. For example, the act of attending to a sensory event has been shown to produce an increase in cerebral blood flow in the primary somato-sensory area (Roland, Skinhoj, Lassen & Larsen, 1980). The use of magnetic potentials has indicated some evidence favoring hippocampal generation of the late positive wave discussed above (Okada, Kaufman & Williamson, 1983).

The use of brain injury cases also provides an opportunity to develop links between facilitations and inhibitions in the performance domain and underlying neural systems. It has been argued that brain injury serves to disrupt computational modules or to disconnect them, not to create new modules (Coltheart, 1985). Thus, one ought to expect cases of brain injury to disrupt the mental operations performed by the area of the brain that is damaged. There are, of course, several problems inherent in this logic. Lesion work has often been faulted because it may be used to suggest that the absence of a function following a

lesion means that the function was located in the lesioned area. Certainly this is not a necessary conclusion, but the fact of deficts following lesions is germane to the localization issue and provides direct evidence that the brain treats that function as a separable entity. Often following traumatic brain injury there are effects which occur at locations far removed from the original lesion location. These have been studied by EEG (Gummon, Dustman & Kearney, 1984) and by change in local glucose utilization (Duell & Clark, 1984). To some extent they are reduced with time as the brain readjusts to the injury. However, they do represent cautions about the degree to which a defict can be localized by the lesion method alone. It seems to me that the general framework with which we are working encourages the investigation of links at each level and reduces the over emphasis on the location issues as the major reason for studying connections between neural systems and information processing modules. In addition the effort to go from findings of lesioned patients to predictions about normal performance provides a check on some of the problems of the use of brain injured populations.

Computational Analysis of Visual Spatial Attention

The idea on which our analysis is based is very simple. The act of attending to something provides priority of that information to a large variety of non habitual or arbitrary mental operations. We often abbreviate this sentence by saying it improves access to consciousness. We measure such access by time locked improvements in the efficiency of detecting or

identifying the stimulus event. This logic is quite straightforward when detecting a visual stimulus involving overt movements of the eye. If the eyes are focussed on a stimulus we observe an increase in efficiency in the sense of visual acuity. We can be aware of fine detail which would be impossible if we were not looking directly at the stimulus. When attention is shifted covertly efficiency can be measured by the priority given that event over other possible events. We often measure priority by the speed of responding to that stimulus. Thus, when attention is drawn covertly to a visual location, responses are faster (Posner, 1980) and more accurate (Bashinski and Bachrach, 1980; Remington, 1980). If attention is drawn to a category (e.g. animal), items which are central to that category can be classified faster than items peripheral to the category or in other categories (Neely, 1977; Rosch, 1973). Thus, following a prime "animal" subjects can classify the stimulus "dog" as a word faster than they can "tin" (Neely, 1977). This can be done internally as when the subject is taught to think body part when the prime is animal and the target word "leg" is then facilitated. These changes in facilitations and inhibitions occurring in the first second following a semantic or visual cue allow us to measure components of an attention shift.

What are the computations that lie behind these attention shifts? We argue that three operations are involved; these are: disengage, move and engage (see Figure 2). Suppose you are

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Insert Figure 2

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currently attending to some location other than the one cued. It is first necessary to disengage attention from its current focus. The time to disengage attention increases with the depth to which it has already been committed (LaBerge, 1974). When the task to be performed is more difficult, time to disengage is increased. Thus, there is no fixed time to disengage. This feature of human attention is quite different from a simple spotlight or interrupt in a digital computer. Nonetheless it is of great importance. If a person is expecting a visual target to occur somewhere in the field but has no idea where, his attention is committed only to the visual modality and not to a location. Such an attentive state is known to facilitate the firing rates of parietal cells (Mountcastle, Anderson & Motter, 1981). This state becomes a baseline against which to evaluate both the facilitation due to attending to a target and the cost or inhibition which commitment to a location produces on targets at unexpected locations. As a practical matter, it is often a serious problem to determine the appropriate baseline condition against which to measure costs and benefits of cues (see Jonides & Mack, 1984 for a review).

If a target occurs outside of the focus of attention it is necessary to disengage from the current focus and to move attention to the target. There has been considerable argument about how this operation is performed. In studies of visual imagery and mental rotation there has often appeared to be a linear relationship between the distance moved or the degree of rotation and the time to perform the operation (Kosslyn,

1980). There is also sometimes evidence for an increase of reaction time with distance in shifts of visual attention (Downimg & Pinker, 1985; Tsal, 1983) and other times not (Posner, 1978). However, the increase of reaction time with distance, while a convenient feature, is not a necessary condition to define an analog movement. It is well known that the time to move the hand from one target to another will only increase with distance if the accuracy of termination is held constant (Fitts, 1954). Studies that ask directly whether intermediate location are facilitated at intermediate times between leaving one focus and arriving at the target are more direct tests of analog operations (Shulman, Remmington & McLean, 1979). It is quite likely that there are analog properties to attention movements that are not linear with actual distance, but depend both on the degree of clutter in the field, crossing the midline, and the eccentricity of the starting and finishing location. Downing and Pinker (1985) have argued that such movements are related to the number of receptive fields between the start and finish locations. If this turns out to be correct it will be an important link between the structure of the underlying physiology of the visual system and attention.

When attention reaches the target location it must be engaged. It is clear that such engagement can occur prior to the target arrival since if one is cued to attend to a location, there are costs when a target occurs elsewhere.

How large a part of the visual field is represented by the focus of attention? This has been a widely disputed issue. For

example, Hughes & Zimba (1985) have argued that attention acts simply by inhibiting the hemifield to which one is not attending. Other investigators have found conditions in which the hemifield to which attention is summoned by a target is inhibited over all other parts of the field (Marzi, 1983). Still others have found a facilitation localized to the neighborhood of the target with an inhibition which is stronger once one has crossed the midline (Downing & Pinker, 1985; Posner, 1985). These disputes indicate the complexity of the overlapping processes that accompany a shift of attention.

Our basic approach to these complexities has been to attempt to deal with a functional system that can both account for the various findings and obeys other properties that we have come to associate with attention.

According to this functional viewpoint (Posner & Cohen, 1984) there are three basic components that occur simultaneously when attention is summoned by a cue located in the neighborhood of a likely target and these add to determine the net increase in efficiency. First, the cue increases the alertness of the person because he now expects a target. It is known from previous work that alertness is not spatially selective and works to potentiate all targets following the cue.

Second, the cue initiates a spatially selective movement of visual attention to the cued location. Such attention shifts are not fully automatic in the sense of being unavoidable (Posner, et al, 1984a), but they occur with little effort if the subject does nothing to avoid them (Jonides, 1981). We are not sure how tight

the attentional focus is, but we suspect that it depends both on eccentricity and on the precision with which the cue localizes the target. Thus, in a completely blank field one may find a uniform effect over a whole hemifield in comparison to the opposite field. However, when the field has many elements (Downing & Pinker, 1985) the facilitation may be localized to a few degrees. Indeed, Erickson & Hoffman, 1978 showed that when responding to single letters subjects appear to be sensitive to all object within about 1 degree of the focus of attention. LaBerge (1983) has shown that when being sensitive to a whole word the focus of attention is broader than attending to a single letter. Thus it is clear that the focus of attention can vary considerably. It appears very likely that facilitation of an entire hemifield may be a limiting case in an empty field when there is a great deal of uncertainty about target locations.

Third, the occurrence of a cue in the periphery initiates two forms of inhibition. The first form (cost) is a consequence of orienting attention to the cue. Once attention is engaged at the cued location all other locations will be less efficient (inhibited) than they would have been if no such orienting had occurred. This form of inhibition is not spatially selective except in the sense that it is not present within the focus of attention. A second form of inhibition we call inhibition of return. It is not clear whether it is initiated by the sensory event or by the act of attending to that event (Maylor, 1985), but it is shown most clearly if one summons attention to a location and then returns it to a neutral location. The

efficiency at the previously cued location is reduced with respect to comparable locations in the visual field for one to two seconds. The overlap between facilitation due to orienting of attention and the specific inhibition of a cued location helps to explain the conflicts in the literature. Sometimes the cued location is handled more efficiently than other locations, sometimes less efficiently, depending upon the balance between the two components.

The effect of any peripheral visual event is complex. It alerts the organism, provides the basis for orieting of attention and begins a process of reducing the efficiency at the location which has been cued.

Is there any advantage to this constellation of internal events produced by a peripheral cue? At first it seemed to us very puzzling that such a complex of events should accompany the presentation of a cue. Later we were able to propose a rationale for these effects (Posner & Cohen, 1984).

Our theory rested in part on our findings that the facilitation obtained from a peripheral cue moved with the eyes as though it was mapped in retinal coordinates. It was clear that the effect was not on the retina since it could be obtained in a stereoscope. However, many visual maps perserve the coordinates of the retina so it might not be too surprising that a visual attention effect also did. On the other hand inhibition of return appeared not to move when the eyes did as though it were dependent on the coordinates of the environment. When we move our eyes the objects of the world appear to maintain their

locations. Thus, many psychological phenomena maintain the coordinates of the environment as we move about. It seemed to us important that one of our effects (facilitation) is retinotopic and the other (inhibition of return) is environmental in this sense.

These findings led us to suppose that the facilitation effect serves to improve the efficiency of target detection within a fixation. It is designed to allow us to give momentary priority to an area of the visual field as, for example, when we carefully examine the nose within a face. If the task demands high acuity we are likely to move our eyes to the interesting location and thus produce a reorienting of attention back to the fovea. In reading for example, the reduction of acuity with eccentricity may be the cause of the eye movement (Morrison, 1984). Facilitation allows a temporary emphasis to go on outside the center of fixation. Since it serves only within a fixation it works in retinotopic coordinates. When the eyes move, attention is drawn back to fixation.

We speculate that the inhibition of return evolved to maximize sampling of novel areas within the visual environment. Once the eyes move away from the target location, events that occur at that environmental location are inhibited and we find one is less likely to move the eyes back to them (Posner, Choate, Rafal, Vaughn, in press). This would reduce the effectiveness of an area of space in summoning attention and serve as a basis for favoring fresh areas at which no previous targets had been presented. The long lasting nature of inhibition of return (1.5

sec) ensures that two to three eye movements are biased against a return.

The organization of facilitation and inhibition outlined above seemd to us to represent an exquisite functional adaptation to the needs of the visual world. There has been much discussion within psychology and physiology about the use of retinotopic and environmental coordinates for the mapping of visual phenomena. Physiologists usually stress the presence of many retinotopic maps early in the visual system, however, psychologists are aware that many subjective phenomenon are mapped environmentally. Our finding of the close relationship of both types of mapping within the spatial attention system appears to be a special opportunity to understand how retinotopic maps relate to psychological performance.

Several important issues emerge from our model system for the study of spatial attention. First, it appears that the performance of people can be used to study time locked shifts of efficiency that relate to visual cues and eye movements. While we can describe these in terms of three logical computations involved in movements of attention at another level several component facilitations and inhibitions occur simultaneously each locked to the occurrence of the cue. A theory that relates these components to performance is hard to test because of the complex overlapping nature of the effect produced by the cues. No doubt several different cognitive theories might describe what we have found. Perhaps this represents something of the intrinsic ambiguity obtained when one only has stimulus and response with

no way of getting intervening steps in the computation. In order to examine these changes further it is important to look at the neural machinery which is involved.

Neural Systems of Visual Spatial Attention

Alert Monkeys

Two areas of the monkey brain have cells whose firing rates are enhanced selectively when the monkey's attention is directed to their receptive fields (Wurtz, Goldberg & Robinson, 1980). In one area, the superior colliculus, the selective enhancement occurs only when attention is directed overtly via eye movements. In the second area, the posterior parietal lobe, selective enhancement occurs both when attention is directed overtly and when the monkey is required to maintain fixation while attending to a peripheral target.

Is selective enhancement in the monkey related to the mental operations of human covert attention being described in the last section of this chapter? If that proves to be the case, we would have advanced our goal of providing useful links between the levels of performance and those of cellular activity.

In the last section I reviewed experiments using both central symbolic cues and cues at the spatial position of the target which obtained facilitation in reaction time and thresholds at the cued locations. In addition, when covert attention is maintained over a steady stream of signals there is a negative shift in electrical activity at the scalp for targets at the selected position (Harter & Aine, 1984;

Naatanen, 1982; Van Voorhis & Hillyard, 1977). These results seem to suggest that such cues cause a change that both facilitates the efficiency of detecting a target and alters some aspects of brain activity.

One feature of these results is that the changes are tightly time-locked to the cue's occurrence. The presentation of a peripheral cue appears to produce improvement in reaction time when it leads the target by as little of 50 millisec (Posner, 1980). Processing negativity affects the signal from the selected location by about 120-150 millisec. This can be compared with selective enhancement of parietal cells which occurs about 75 millisec after target input. When attention is shifted to a peripheral target in preparation for an eye movement facilitation occurs about 150 millisec prior to the onset of the eye movement (Posner, 1980; Remmington, 1980). The time course of this effect is markedly similar to the selective enhancement of cells in the colliculus which occurs about 150-200 millisec prior to the onset of the saccade (Wurtz, Goldberg & Robinson, 1980).

The time course of single cells, event related potential and performance changes are roughly similar and this provides one source of evidence on the relationship between selective enhancement of single cells in monkey brains and facilitation of human performance. Somewhat more direct evidence may be obtained through the study of patient populations suffering from brain injury to midbrain and cortical areas.

Patients

There is a long clinical history documenting the finding that lesions of the posterior part of one hemisphere can cause a severe deficit in reporting information on the side of space opposite the lesion (DeRenzi, 1982). One aspect of this syndrome is a reduction in eye movements to the side of space opposite the lesion and a reduced ability to notice or report visual stimuli there. This neglect of visual information contralateral to the lesion occurs most strongly when the patient is confronted with simultaneous lateralized visual stimuli. In this case the stimuli contralateral to the lesion is frequently not reported (extinguished). The phenomenon of neglect can arise from unilateral lesions of the midbrain and thalamus as well as from a variety of cortical lesions. However, clinical observation seems to suggest that parietal lesions on the right side are the most frequent area of damage leading to neglect and extinction (De Renzi, 1982).

For a variety of reasons, clinical researchers have related the neglect phenomenon to a reduced ability to orient covertly or overtly to stimuli opposite the lesion. This account is supported by the finding that stimuli from the neglected side do show the exogenous components of event related potentials although frequently reduced in amplitude. Neglect of contralateral stimuli tends to be variable, sometimes quite strong and at other times much weaker. Contralateral stimuli can often be seen clearly when presented alone and can be used when patients are required to determine if pairs of stimuli presented

across the mideline are identical or not (Volpe, LeDoux & Gazzaniga, 1979). All of these facts point to the idea that although stimuli contralateral to the lesion do have some effect on cortical systems they often fail to reach systems that subserve conscious awareness.

These results are not unlike those found in normal subjects when they are heavily baised toward one source of sensory signals. For example when paying attention to an auditory messsage presented to one ear it is not unusual for events presented to the other ear to be unreported or to be noticed only when they are of special significance (e.g. the person's name). Humans have been shown to have such a strong bias toward visual stimuli that simultaneous auditory events of equal strength can be missed entirely if subjects are led to expect that only a single modality will be perceived (Colavito, 1974; Egeth & Sager, 1977). Reports of these experiments are usually met with surprise. Attention is usually directed toward new stimuli with great efficiency, yet under special circumstances stimuli that we are clearly capable of sensing do not reach consciousness.

Both the alert monkey work and clinical observations then, suggest that studies of patients with damage to the midbrain in the area of the superior colliculus and to the parietal lobe might be helpful in determining how the mental operations involved in covert orienting of attention are controlled by neural systems. The emphasis in reviewing this material is on the dissociation of cognitive components not upon anatomical

localization. We conducted studies that have used the performance methods discussed previously with certain selected patient populations. While the lesions of these patients are not localized to a small area they can provide evidence on whether the elementary operations and components facilitations and inhibitions described with normals are affected differentially by lesions of different brain areas.

Midbrain effects

It is well known that damage to the superior colliculus in animals produces a transient loss in saccadic eye movements that after recovery may only appear as increased latency. A neurological disease called progressive supranuclear palsy, which involves degeneration of the colliculus and surrounding structures, is also known to produce a loss of the ability to perform saccadic eye movements in humans. It is also known that such patients have trouble in performing tasks that require orienting toward events in social situations (Rafal & Grimm, 1981).

Covert visual orienting can be studied in such patients by cuing them to shift attention in directions where saccades are not possible and observing time-locked changes in the efficiency of reporting targets at those locations (Posner, Cohen & Rafal, 1982). It was found that these patients could shift attention in directions even when they could not voluntarily move their eyes in that direction. However, detailed comparisons of the speed of covert orienting suggested that it was retarded in the direction of the most severe eye movement paralysis. The damage to the

saccadic system seemed to effect the latency of covert orienting. The specific effect was to delay the advantage for the cued over the uncued trials as though the damage effected the speed of moving from one attended location to another location irrespective of whether the trial was a cued or uncued one. These effects were not general results of similar degenerative disorders since they were not found in Parkinson's patients who have a related degenerative process but do not share the paralysis of the saccadic eye movement system.

In addition, the PSP patients showed a loss of the form of inhibition which we call inhibition of return (Posner, Choate, Rafal & Vaughan, in press). If their attention was summoned up or down by a peripheral cue from fixation to the target location and then back to fixation they showed equal reaction time in returning to the previously uncued location as to the cued location (Posner, et al, in press). This was quite different from normals from what happened to these same patients with horizontal targets and all other patient groups studied (Parkinsons, parietal, frontal). Our previous work with normals had led us to speculate that inhibition of return was functionally related to the eye movement systems (Posner, & Cohen, 1984). Thus, finding a loss of this effect in patients with known deficits in the saccadic system seems a confirmation of the hypothesis and one that furthers the relationship between cognitive theory and neuropsychology outlined by our general framework.

A role for midbrain systems in covert attention movements was also confirmed in a study of split brain patients (Holtzman, Sidtis, Volpe, Wilson & Gazzaniga, 1981). It was found that cues indicating where in space a target might occur were successful in directing attention irrespective of whether they were presented to the same or opposite hemisphere that received the target. However, this system was more restrictive than the cortical system (Holtzman, 1985). It seems likely that the midbrain plays a role in moving covert attention from one location to another in much the same way as it does for eye movements. As with eye movements, degeneration in this area increased latency, but did not eliminate covert attention shifts. The finding that latency is slowed by midbrian lesions suggests that the midbrian system is a subordinate component of a larger system that involves cortical centers as well (Mesulam, 1981).

Cortical Lesions

An impressive aspect of parietal patients is their tendency to be unaware of signals that occur on the side opposite the lesion. Although this hemi-inattention can occur in any modality we shall confine our discussion of it to the visual modality. Clinical investigation of this phenomena has been well summarized by De Rezzi (1982).

These clinical observations together with animal work suggested that parietal deficits might be thought of as a reduction in attention, arousal, or orienting (DeRenzi, 1982). In addition, lesions of the parietal lobe appear to reduce the processing negativity to selected auditory stimuli (Knight,

Hillyard, Woods & Neville, 1980). Unfortunately, these data do not provide an analytic treatment of how the lesion acts to produce neglect or extinction. According to our idea, movements of spatial attention depend upon a sequence of three elementary mental operations (See Fig 2). It is impossible to judge from clinical data exactly how these operations might be affected by the parietal lesion. However, features of the clinical syndrome do seem to argue that the lasting effects of the lesion may be largely on the disengage operation. The reason is the finding that unilateral stimulation can draw the subject's attention to the side opposite the lesion but with bilateral presentation the same stimulis is not perceived (extinguish). Moreover, patients with parietal lesions can often compare stimuli on the two sides (Volpe, et al., 1979) even though they show clinical extinction. This argues that information on the side opposite the lesion may receive a high level of analysis but is not perceived when there is competition. Such observations suggest that a stimulus on the side opposite the lesion cannot grab hold of attention, when attention is already elsewhere engaged.

These speculations received support from experimental work (Posner, Cohen & Rafal, 1982; Posner, et al, 1984c). In these studies patients are given a cue followed by a target to which they respond by pressing a single key. Parietal patients often have a general advantage in reaction time for those targets that occur ipsilateral to the lesion in comparison to those that occur contralateral to the lesion. However, for many parietal patients

there is little or no difference between the two once a cue has been presented 50 msec or more prior to the presentation of the target. When attention is drawn to either side, these patients have nearly equal abilty to detect the target. Thus the ability to engage the target once attention is properly directed is not necessarily interrupted by parietal lesions although it often somewhat affected.

Striking results occur on trials in which attention is cued to the side of the lesion and the target is presented on the side opposite the lesion. In some cases, targets show extinction, that is, they are missed entirely by the subject (Posner, Cohen & Rafal, 1982). In other cases, these targets are not completely excluded from consciousness, but show greatly delayed reaction times, sometimes two to three times the normal reaction time. The results suggest that the elevation in latency is simply a less severe form of complete exclusion from consciousness. Patients who miss signals completely when they remain present in the field only briefly will report them when they remain present for a second, but only with a greatly increased latency. The idea that a latency increase is a less severe form of difficulty than extinction fits with the account of covert orienting discussed previously.

It is also possible to show that the pattern of increased reaction times to contralateral targets following miscues does not depend upon the miscue being ipsilateral to the lesion. Rather, cuing the patient with a central arrow which directs attention to the side opposite the lesion is sufficient to

produce the same greatly increased reaction time to targets that occur opposite the lesion. Similarly, a central brightening a function which draws attention to fixation, even if it tells nothing about target location (neutral cue), produces a similar increase in reaction time to targets opposite the lesion (Posner, et al, 1984c). The neutral cue result shows that neither a probability difference nor a stimulus ipsilateral to the lesion is necessary to produce the greatly elevated latency related to extinction. This result is different from that obtained from midbrain lesions. It suggests that a powerful effect of the parietal lesion is upon the disengage function. Patients whose attention is engaged at any other visual location including fixation show a loss of efficiency on the side opposite the lesion.

In terms of the framework (Fig 1), presented in the introduction and the three mental operations involved in movements of attention (Fig 2), it is now possible to propose that the midbrain lesions primarily affect the move operation, while the parietal lesion relates to disengaging attention. This result would be similar to what one finds with eye movements, where lesions of colliculus produce difficulties primarily in the execution of the eye movement rather than in the command that generates the movement.

In addition to its affect on the disengage operation it is likely that parietal damage also affects the move function to some degree. It has been widely understood that right parietal lesions have difficulties in dealing with the left side of

objects in either the good or bad visual field. This led Kinsbourne (1977) to suggest that each parietal lobe controls orienting toward the opposite side of space, irrespective of the visual field in which the information was located. Parietal lobe lesions can reduce the likelihood of eye movements toward the contralateral side. A similar role for covert attention movements would be in accord with general nervous system principles suggesting similar control systems are frequently repeated at higher levels.

Clinical literature provides evidence that neglect and extinction may arise from lesions at many sites provided they are unilateral. On the other hand, the relative specificity of the single cell data in showing selective enhancement only at collicular and parietal sites suggests a much more restricted locus for the covert orienting operation. Tests to date suggest that neither temporal nor frontal lesions produce the same pattern of RT effects on covert orienting that have been discussed for the parietal lesion. Although it is quite possible that such lesions influence many aspects of the clinical syndrome of neglect, covert orienting deficits are more restricted.

The work described on visual spatial attention suggests that the act of attending can be broken into several component computations. These components can be revealed in performance studies in terms of overlapping patterns of facilitation and inhibition that accompany the performance of the mental operations. It has been shown that these components are affected differentially by lesions of the midbrain and cortex. Thus, the

brain appears to perform a simple attentional act by the orchestration of a network of cortical and subcortical systems. Visual-spatial attention is not performed by a single center nor is it a general property of the visual system or of the brain as a whole. Rather, it is an act consisting of components which can be differentially affected and lead to quite different behavioral deficits. Visual-spatial attention, however, is a very small part of attention as a whole. In the next section we present some approaches to the issue of how this form of attention relates to other forms.

Hierarchies of Distributed Networks for Spatial Attention

Is visual attention a separate module which controls the allocation of resources within that domain or is it merely a part of a more general system involved in attention to space? In cognitive psychology this issue concerns the unity attention. Some authors have argued that interferences caused by attention are severe only when they occur within the same modality or cognitive domain (Allport, 1980). Other authors have favored the idea of a single channel or limited processor at least for the set of operations we have defined as conscious (Posner, 1978). In 1978 I argued about the importance of a central system to exercise inhibitory control over more local processing in order to dampen the consequences of widespread activation of habitual pathways. Unfortunately the evidence form strictly cognitive experiments has not been decisive (Kahneman & Treisman, 1985).

There often appears to be more interference when tasks depend on similar processors, but even when they do not, some residual interference usually remains (McLeod & Posner, 1984).

One way of viewing this issue consistent with much cognitive theory (McKay, 1983; Rummelhart & McClelland, 1984), is to suppose that attentional modules are arranged in a hierachical fashion (see Fig. 3). Thus, there might be a network for the allocation of attention to locations in visual space and a somewhat different but related network for auditory space. However, since both of these networks are spatial, there would also be a higher level system that allocates information to locations in space irrespective of modality. Similarly attention might be allocated to the cognitive system controlling language which then would be subdivided into modality specific systems controlling reading and listening.

Insert Figure 3

There is some evidence from both performance and neurological studies which favors this general idea. In 1978 we (Posner, Nissen & Ogden, 1978) reported that a cue which draws attention to a spatial location was rather inefective when the person did not know the modality of the target (visual or tactile). When both modality and location were known the cue became quite effective in improving the efficiency of performance. Thus locations seem to be organized by modality.

This result fits with recent findings by DeRenzi, et al (1984) relating to clinical extinction found in parietal patients. They showed that while both visual and auditory extinction could be found the two were independent. This suggests that at the level of parietal lobe function engaging a visual location has only minor effects on the efficiency of auditory detection and the reverse.

There is of course nothing very surprising about a view that spatial cognition represents a multimodal system toward which attention can be directed. What seems most interesting is to compare the relative influence of modality (e.g. auditory vs visual) and cognitive system (e.g. spatial vs language) in influencing the direction of attention. In a series of studies with normals (Posner & Henik, 1983) and parietal patients (Walker, Friedrich & Posner, 1983) we have used a spatial version of the stroop effect to study this issue.

In these experiments subjects are instructed to respond either to the visual words left or right, to visual locations on a CRT, to visual symbols (arrows pointing to the left or right), or to auditory words (left or right) that might be presented to the left or right ear. In different experiments manual or vocal responses have been used. In work with normals (Posner & Henik, 1983), we compared irrelevant dimensions which used either the same cognitive system but a different modality than the attended event, with those in the same modality but a different cognitive system. When a person is to deal with a visual or auditory word

the extent of facilitation or conflict in RT from words in the opposite modality is much greater than from spatial locations in the same modality. A similar result is obtained for the instruction to attend to a spatial location, but in addition auditory location has generally smaller effects than does visual location. There seems to be evidence from these results that stimuli from a cognitive system, even when they involve different sensory modalities are interacting strongly although not as strongly as if they shared both cognitive system and modality.

The study with patients suggests another sense of separation by cognitive system. Selection by spatial location appears to involve the parietal system irrespective of modality of input. One evidence of this is that lesions of the parietal lobe can produce extinction in visual, auditory or tactile domains depending upon their location (DeRenzi, 1982). Our work has shown that patients with parietal lesions have similar difficulties in directing attention when the cue is (1) at the target location; (2) a central arrow or (3) a word which directs attention to the target. In addition we have studied parietal patients in a version of the spatial stroop in which they are required to respond either to a left or right pointing arrow or to the word left or right. Normals show faster responses to the arrow and much more interference of the arrow on the word than the reverse. Right parietal patients have greater difficulty with the arrow than the word, thus reversing the normal pattern. Left parietal patients show a normal but greatly exaggerated pattern in which the arrow dominates quite strongly over the word

(Walker, Friedrich & Posner, 1983). These data all show the involvement of the parietal system in spatial attention irrespective of input mode.

Non Spatial Selective Attention

We were interested in learning whether this spatial attention system represents an independent module or whether it is part of a more general attention system. We (Posner, Inhoff & Friedrich, in process) designed a dual task for our parietal patients. Each patient was run in the visual-orienting task described previously. In separate blocks they were required either to count backwards from a fixed digit or to monitor a series of auditory words for a target phoneme. These tasks were designed to tap at two quite different cognitive systems. The visual spatial task was known to involve the anatomical network which we have been describing. The two other tasks involved cognitive systems related to language. Neither of the secondary tasks involved the visual modality nor did they require a manual output similar to what was used in the visual orienting task. Thus, as far as we could determine the two tasks were as separte in their cognitive demands as possible.

The results showed quite clearly that the two tasks interacted in an interesting way. Reaction time to visual targets were slowed by the dual task and the use of cues was also clearly retarded since at 100 msec the cues were no longer effective in directing attention to the visual targets. Thus, the language task disrupted the processing of visual targets by

engaging the subject's attention to another cognitive system. A second important point is that this engagement of attention to the language task did not produce any differential advantage of the ipsilateral over the contralateral field. These two results led us to conclude both that visual orienting required access to a general attention system which was also used by the secondary tasks and that this system could not be anatomically similar to the parietal system damaged in our patients. If it were parietal, engaging attention to the language task would have produced the extinction-like reaction time pattern found with visual engagement in which contralateral stimuli are disadvantaged over ipsilateral stimuli.

It appears that in order to engage the parietal based spatial system another system must be free to issue some type of command signal. If this other, more general attention system is involved in generating counts or monitoring language the parietal system does not engage the location of the cue. This finding fits with the ability of parietal patients to perform spatial orienting tasks when they are not engaged. The origin of the improvement in performance due to spatial attention does not appear to reside in the parietal system. The location of the higher level attention system depicted in the top node of Figure 3 remains unclear. The close anatomical connections of the parietal lobe to frontal sites (Mesulam, 1981) and the general effects of frontal lesion on a variety of tasks suggests to us a system which involves frontal areas, but which may be quite distributed.

Conclusions

The goal of this chapter was to outline a general framework for dealing with the relationship of cognition to brain systems. This framework is shown in Figure 1. It is hoped that it provides a method which can be applied to any form of cognition and which will prove useful in discussions of the relationship of cognition to neural systems. The framework provides for empirical investigations at many levels; computational, chronometric, spatial imaging and cellular. It argues for the logical interrelationship of these areas of investigations and provides speculations about how some of the current findings at one level (e.g. pathway facilitation in chronometric studies may relate to findings at another level i.e. processing negativity in EEG studies and selective enhancement of single cells).

We have sought to apply our framework to the issue of selective attention. In the area of visual-spatial attention it has proven possible to relate specific elementary operations (e.g. disengage and move) to identified regional neural systems by the study of populations of brain injury subjects. Studies of cross modality cuing and interference suggest that the parietal system is also related to spatial orienting irrespective of modality and type of cue. Thus we see a cognitive system involving spatial attention, in which somewhat separate modality specific systems are organized. This hierarchical view is illustrated in Figure 3.

We have asked whether the cognitive system subserving

attention to spatial information relates to a more general attention system. The idea of a unified attention system has been quite persistent in studies of human performance and cognition. Our patient studies suggest that spatial attention is a module within a more general system of attention that extends to other cognitive systems as well (e.g. language). While the anatomy of the more general system is unknown, the general framework does suggest the types of studies which may be useful in revealing its anatomical organization.

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Figure 1

COGNITION AND NEURAL SYSTEMS

LEVEL	GENERAL EXAMPLES	COVERT ORIENTING TASK EXAMPLES
TASK	READING, SPEAKING IMAGERY	COVERT ORIENTING
ELEMENTARY OPERATIONS	NEXT, SCAN, NAME, ZOOM	DISENGAGE, MOVE, ENGAGE
COMPONENT ANALYSIS	FACILITATE PATHWAY INHIBIT PATHWAY	FACILITATE LOCATION
NEURAL SYSTEM	PROCESSING NEGATIVITY PET BLOOD FLOW	MIDBRAIN (SUPERIOR COLLICULUS) PARIETAL LOBE
CELLULAR ACTIVITY	SELECTIVE ENHANCEMENT	LIGHT SENSITIVE CELLS

Figure 2

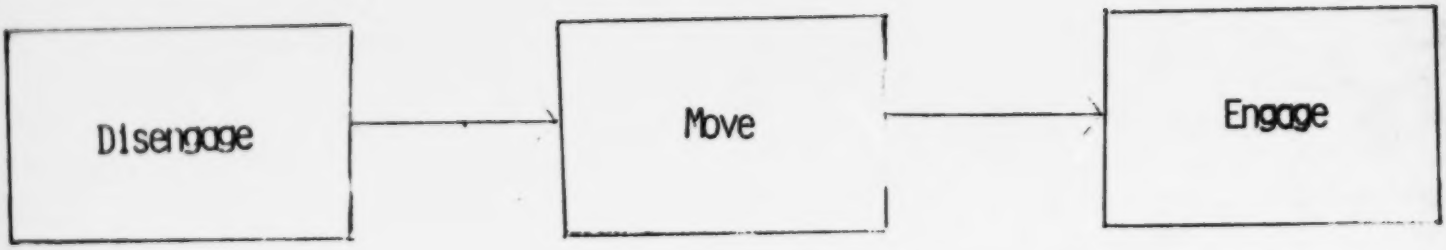
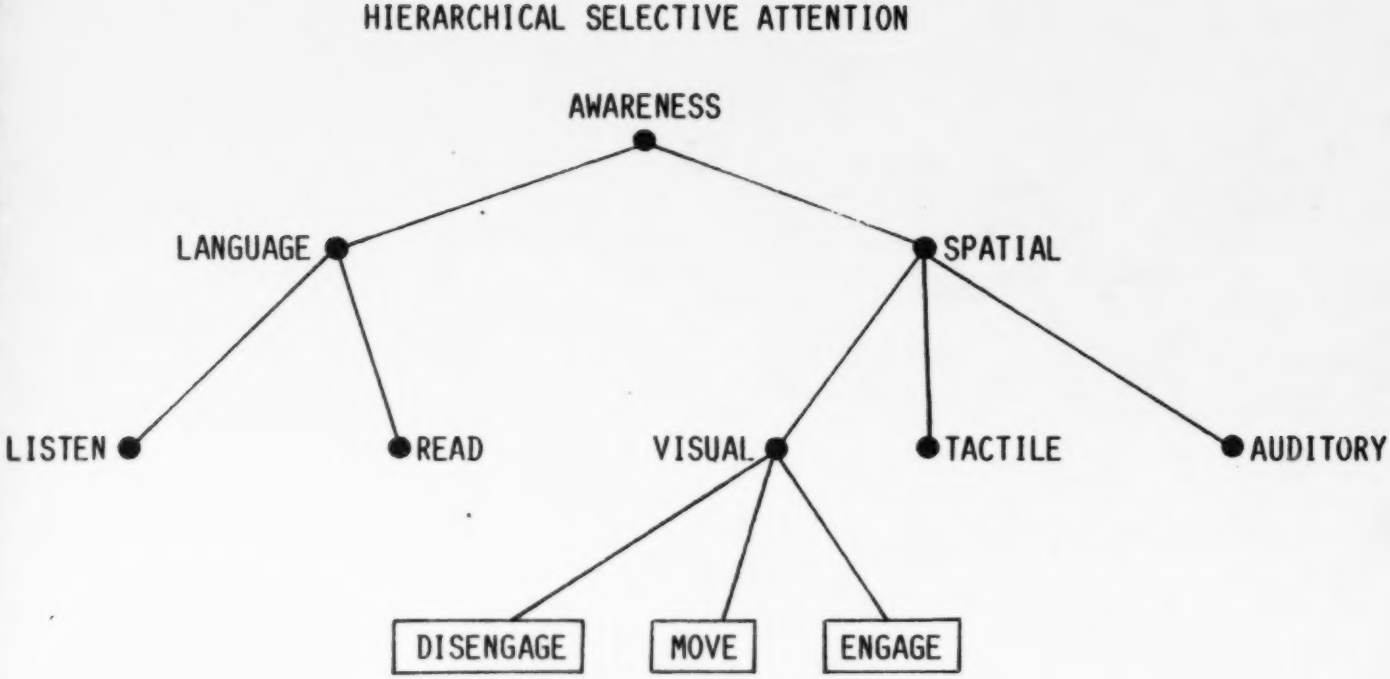


Figure 3


HIERARCHICAL SELECTIVE ATTENTION
AWARENESS
LANGUAGE
SPATIAL
LISTEN
READ
VISUAL
TACTILE
AUDITORY
DISENGAGE
MOVE
ENGAGE